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THE CHALLENGE OF M'LITARY NUCLEAR CONSTRUCTION

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8 March 1972

[redacted]

HUGHES

INDIVIDUAL RESEARCH REPORT

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THE CHALLENGE OF MILITARY NUCLEAR CONSTRUCTION

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This paper provides rationale ~~to~~ support ~~the initiation~~ of ~~a~~ comprehensive program for the development of the capability to use nuclear construction techniques in support of military operations. This military capability which has the potential for providing significant savings in manpower, time, and funds could be developed as a follow-on of the research and development accomplished to date for civil applications. The nuclear construction research programs of both the US and USSR are described in detail with emphasis on the nuclear and chemical cratering experiments that have been conducted and the technology which has been developed. A discussion of the hazardous safety effects resulting from a nuclear cratering detonation is included together with a description of the techniques which have been developed to control these effects and preclude personnel injuries. Potential military construction applications are discussed to include nuclear quarries, harbors, roadway cuts, and inland canals. This paper recommends that the Department of the Army develop and incorporate in its doctrine the use of nuclear construction techniques in support of military operations.

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CHAPTER I

INTRODUCTION

PROGRAM FOR PEACEFUL USES OF NUCLEAR EXPLOSIVES

Since the detonation of the 20-kiloton atomic bombs over Hiroshima and Nagasaki in 1946, tremendous effort has been devoted to perfecting first atomic explosives and then thermonuclear explosives as weapons of massive destruction. In the past ten to fifteen years, however, a portion of the nuclear research and development program has been devoted to peaceful uses of nuclear explosives. This research effort has been sponsored in the United States under the Plowshare Program and in the USSR under the Soviet Program on Nuclear Explosives for the National Economy. The scope of the program has included theoretical and experimental studies to determine the feasibility of using nuclear explosives in construction engineering endeavors.

The nuclear explosives engineering studies to date indicate that nuclear excavation may be several times less expensive than present methods in many applications and that hazardous safety effects can be satisfactorily predicted and controlled. In the United States, however, the research program has been reduced to a minimal effort, due in large measure, to public concern for the attendant safety problems and the limited Test Ban Treaty.[1] The Soviet program appears to be continuing at a significant level of effort.[2]

MILITARY USES OF NUCLEAR EXPLOSIVE ENGINEERING

To date, the emphasis of the US nuclear explosive engineering research program has been placed on civil applications. Little or no effort has been devoted to the use of nuclear explosives for construction purposes in military operations. In World War II, as well as the Korean and Vietnam conflicts, considerable military engineering effort was devoted to the construction of engineering facilities to include harbors, inland canals, roadway cuts, and quarrying. The use of nuclear explosives rather than conventional methods to accomplish these types of construction projects in support of military operations offers a significant potential savings in time, manpower, and funds. While personnel safety will indeed be of concern even in a hostile, military environment; the safety constraints will, of necessity, be less than those that apply to a peacetime, civil environment. Serious consideration should be given, therefore, to adapting and further developing for military purposes the nuclear explosive engineering technology that has been developed to date for civil uses. The development of viable military nuclear construction applications would require further theoretical and experimental research as well as the design and fabrication of nuclear excavation explosives and the appropriate training of military personnel.

MILITARY NUCLEAR CONSTRUCTION RATIONALE

This paper provides rationale for the initiation of a comprehensive program for the development of nuclear explosive engineering technology for military construction purposes as a follow-on to the research and development accomplished to date for civil applications. This rationale includes a discussion of: (a) The nuclear construction technology developed to date; (b) The US and USSR nuclear construction research and development programs; (c) Safety considerations of air blast, ground shock, and radioactivity; (d) Potential nuclear construction applications which are considered to be the most viable for military purposes; and (e) The follow-on research requirements necessary for the development of a military nuclear construction capability.

CHAPTER I

FOOTNOTES

1. K. Parker, "Engineering with Nuclear Explosives--Achievements and Prospects," Journal of the Institution of Nuclear Engineers (Nov/Dec 1971), p. 50.

2. Ibid., p. 52.

CHAPTER II

NUCLEAR CONSTRUCTION CONCEPT AND CRATERING PHENOMENOLOGY

INTRODUCTION

This chapter presents information concerning the basic concept of using nuclear explosives in conjunction with the construction of engineering projects, and briefly describes nuclear crater formation phenomenology and crater geometry.

BASIC CONCEPT OF NUCLEAR CONSTRUCTION

The basic concept of nuclear construction involves the subsurface detonation of nuclear explosives either: (1) to break up and to eject large quantities of rock and/or soil and by so doing to produce excavations which may be used as engineering structures; or (2) simply to break up rock media to produce aggregate for quarrying purposes.

The primary potential advantage of using nuclear methods rather than conventional techniques in conjunction with the construction of engineering projects is economy. The economies that may be realized from applying nuclear excavation techniques to the construction of large-scale engineering facilities stem primarily from three sources:

--The force of the nuclear explosion not only fractures the materials but also ejects it, leaving an excavation which may be used as an engineering structure. This form of excavation would

eliminate mechanical earthmoving which is the major cost item of most conventional excavation.

--Economies of scale are inherent in large nuclear detonations--the higher the yield, the lower the unit cost of energy produced.

--Nuclear explosives are small and compact compared to chemical explosives of comparable yield. Nuclear explosives can be emplaced quickly and cheaply.

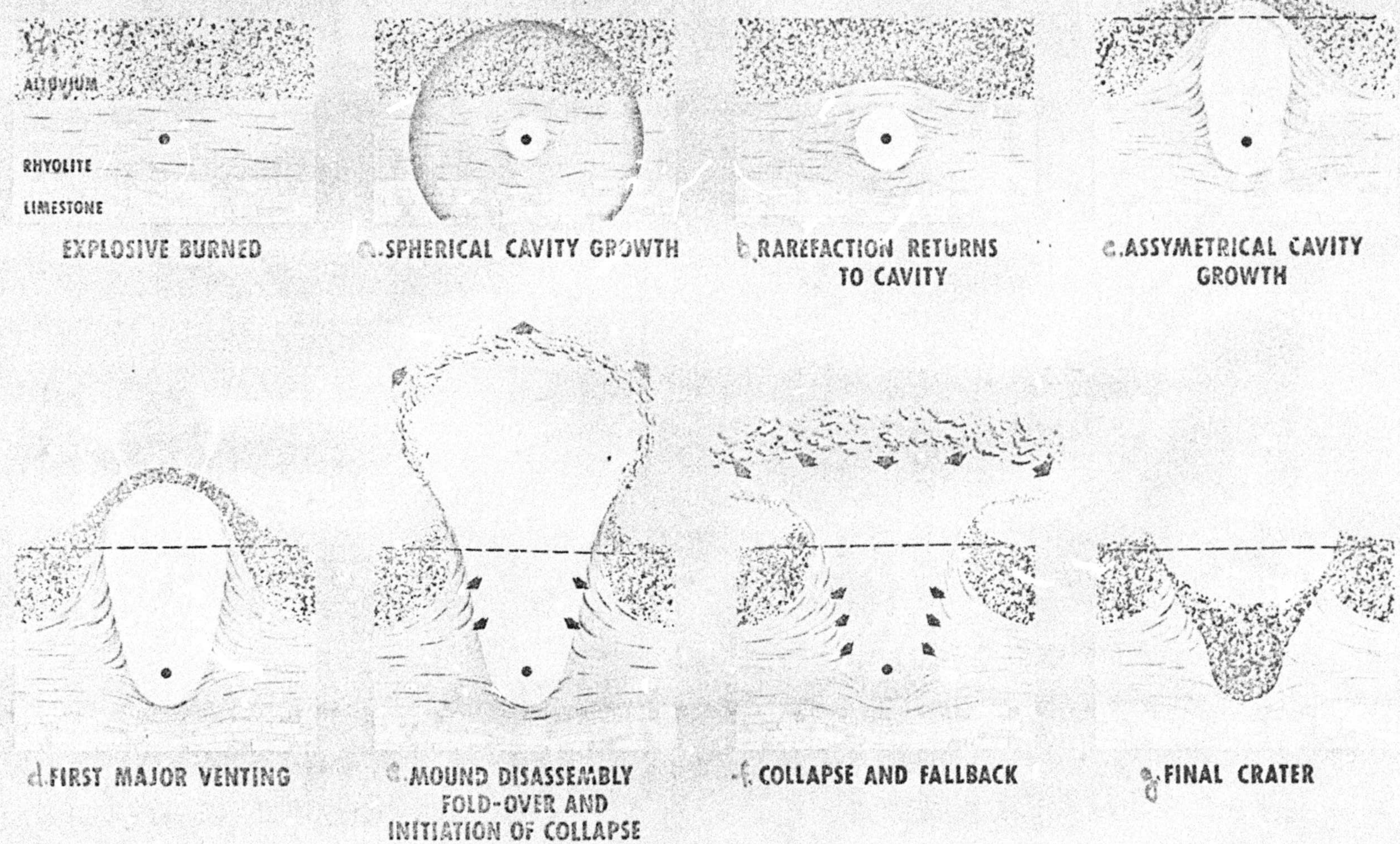
The use of nuclear explosives for construction purposes involves much more than merely producing craters or mounds or rock. One must have knowledge of the phenomenology of crater formation and be able to predict the geometry of the crater in the various geologic media of interest as well as the effect of the nuclear detonation on the immediate geologic environment surrounding the crater. In addition, one must have detailed knowledge of the characteristics and emplacement requirements for nuclear explosives and must understand the safety implications of the radioactivity, the air blast, and the ground shock effects which are byproducts of nuclear cratering detonations. Technical data pertaining to these areas of interest are discussed in this paper.

NUCLEAR CRATER FORMATION PHENOMENOLOGY[1]

Fundamental to the development of techniques for predicting the geometry of nuclear excavations is an understanding of the phenomenology of crater formation. A general representation of the time history of the cratering process is shown in Figure 1.

CRATER FORMATION HISTORY

Fig. 1 (From Ref. 8)



A nuclear explosion releases an extremely large amount of energy from a concentrated source in less than one millionth of a second. This sudden release generates a shock wave which radiates from the point of explosion, transmitting energy to the surrounding material (Figure 1a). This energy is sufficient to vaporize everything in the immediate vicinity of the explosion. As the shock wave expands beyond the vaporized region, its intensity diminishes. It creates successive zones of melted, crushed, and fractured rock, beyond which only elastic deformation occurs. When the shock wave reaches the surface (Figure 1b), a tensile wave is reflected, which causes spalling at the surface and fractures the underlying rock as it travels downward (Figure 1c).

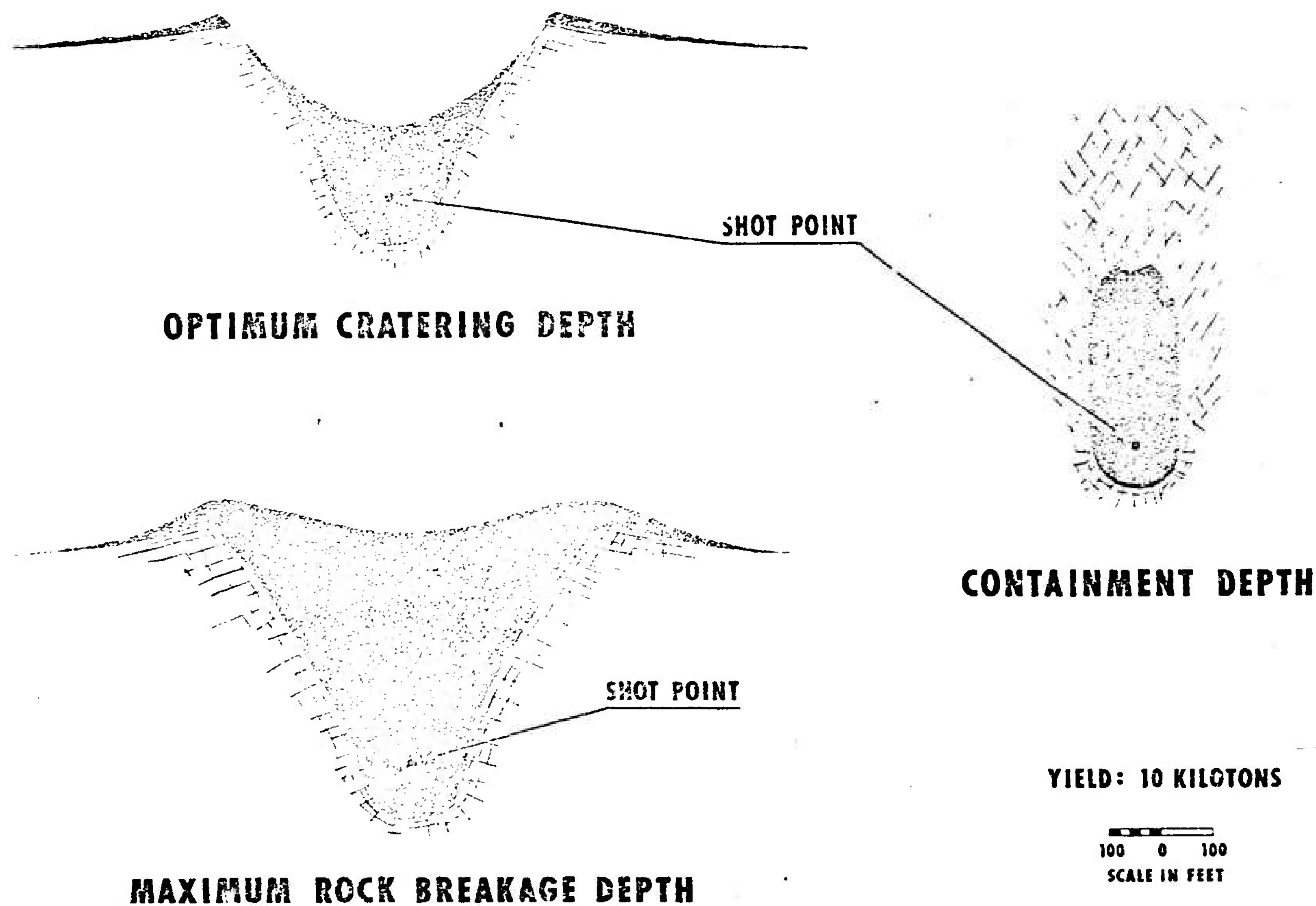
Generation of the shock wave is followed immediately by the expansion of a cavity containing vaporized rock and other gaseous products of the explosion. The cavity grows spherically until it meets the downward-moving tensile wave which relieves the stresses on its upper surfaces. This causes the cavity to expand preferentially toward the ground surface, further accelerating the material already set in motion by the shock wave. As the cavity continues to expand upward, the ground surface above begins to rise. A mound forms (Figure 1d) and grows until it breaks up (Figure 1e) and the underlying material, accelerated by expanding gases, is thrown upward and outward in ballistic trajectory. Some of this material, referred to as fallback, drops into the cavity; while the remainder, referred to as ejecta, falls outside (Figures 1f and 1g).

The relative importance that each of the mechanisms plays in producing craters varies significantly with the depth of burst of the nuclear device and the geologic medium in which the detonation occurs. In addition, the size of the crater produced varies greatly with the depth of burst of the explosive. As the depth of burst increases with reference to the ground surface, apparent crater dimensions increase to a maximum at some optimum depth then decrease until a depth of burst is reached at which no crater is formed.

Another mechanism which can produce a crater is that of "subsidence." This phenomenon occurs when the device is buried too deeply to form a crater ejecting material out of the cavity. Subsidence results when the crushed and fractured material above the detonation point collapses and falls into the void created by the explosion. The collapse progressively works toward the surface and a "chimney" of rubble is formed above the shot. The surface manifestation of this collapse is a subsidence crater. It is also possible, however, that the collapse of the cavity roof will not extend to the surface because of bridging by a competent rock layer or because the void fills with bulked, dislodged rock before it propagates to the surface. Figure 2 shows schematic representations of the variation in cratering effects resulting from the detonation of a nuclear explosive at various depths of burst.

EFFECTS OF NUCLEAR EXPLOSIVES BURIED AT VARIOUS DEPTHS

Fig.2 (From Ref 8)



CRATER GEOMETRY[2]

A few basic definitions are required in order to work with cratering data and to understand the engineering significance of the various crater zones resulting from a subsurface nuclear detonation. Figure 3 shows the cross section of a typical crater and the adjacent zones of disturbance. Characterisitc features of a crater are briefly described below:

The apparent crater is the portion of the visible crater which is below the predetonation ground surface. The apparent crater would be the net design excavation for most engineering applications.

The apparent lip is the portion of the visible crater above the predetonation ground elevation. The apparent lip of the crater is composed of two parts, the true lip and the ejecta. The true lip is formed by the upward displacement of the ground surface and the remainder of the apparent lip results from deposition of ejected material on the true lip.

The true crater is defined as the boundary (below predetonation ground level) between the loose, broken, disarranged fallback materials and the underlying rupture zone material which has been crushed and fractured, but has not been significantly displaced or disarranged. The true crater boundary is not a distinct surface of discontinuity, but rather a zone of transition between rupture zone and fallback materials.

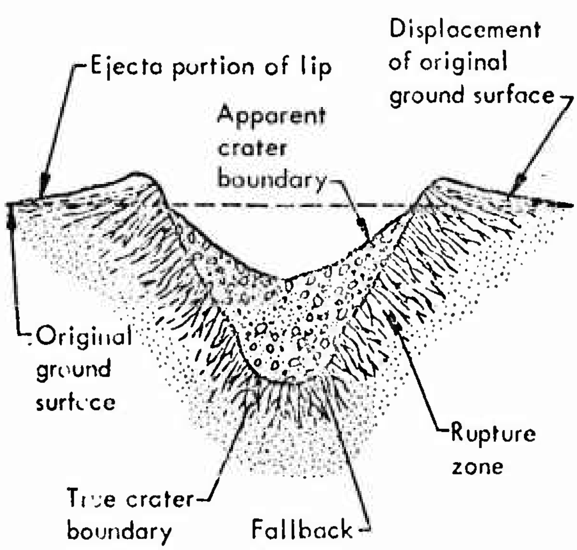


Fig. 3 - Cross section of typical crater (From [illegible])

The *fallback* consists of natural materials which have experienced significant disarrangement and displacement and have come to rest within the true crater.

The *ejecta* consists of material thrown out above and beyond the true crater.

The *rupture zone* is that zone extending outward from the true crater in which crushing and fracturing have occurred. In this zone, displacements and changes in density are evident but the material remains basically coherent in contrast to the disarranged fallback materials.

CHAPTER II

FOOTNOTES

1. John Toman, Summary of Results of Cratering Experiments (1969), pp. 2-4.

2. Bernard C. Hughes, Nuclear Construction Engineering (1968), pp. 23-24.

CHAPTER III

UNITED STATES NUCLEAR CONSTRUCTION RESEARCH AND DEVELOPMENT PROGRAM

INTRODUCTION

Over the past 15 years, the United States has devoted considerable technical effort and funding to developing the technology of engineering with nuclear explosives. The US has spent approximately $175 million on this research effort under the auspices of the Atomic Energy Commission in conjunction with the US Army Corps of Engineers. This expenditure has involved the conduct of 22 tests of nuclear explosives and their engineering effects.[1] The research program has included studies of both contained applications in which the nuclear energy is used to alter only the subsurface environment and cratering or mounding applications in which the nuclear energy vents through to the atmosphere and thus creates an excavation which can be used as an engineering structure.

The contained applications pertain primarily to potential industrial applications such as:[2]

--Natural gas or oil stimulation (increased production from "tight" fields)

--Liberation oil from shale

--Natural gas or oil storage

--In-situ leaching of oils

--Waste disposal

Since these contained applications have little or no potential for use as military construction projects, they will not be discussed in any further detail in this paper.

The cratering or mounding applications which have been investigated include:[3]

--Water reservoirs in craters and behind crater lip dams

--Canals

--Harbors

--Overburden removal for mining

--Railroad and highway cuttings and embankments

--Quarrying

These applications have significant potential for military construction projects. This chapter, therefore, will describe in detail the US research and development efforts pertaining to cratering or mounding applications.

JOINT ATOMIC ENERGY COMMISSION-CORPS OF ENGINEERS RESEARCH EFFORT

In 1957, the Atomic Energy Commission (AEC) initiated its peaceful uses of nuclear explosives program, commonly referred to as the Plowshare Program.[4] A portion of this program was devoted to the development of nuclear explosives and technology which could be used in the excavation of large-scale engineering projects. The primary agency involved in this AEC research effort was the Lawrence Radiation Laboratory (LRL) located at Livermore, California.[5] LRL is a University of California

facility operated under contract to the AEC. AEC nuclear excavation research efforts consisted of:

--Conduct of nuclear cratering experiments to provide empirical data pertaining to nuclear excavation technology;

--Development of methods for predicting the size and shape of nuclear craters;

--Development of nuclear explosive devices which minimize the release of radioactivity, specifically for nuclear excavation applications; and

--Prediction and control of the effects of radioactivity, airblast and ground motion on man and the environment.

In 1962, the US Army Corps of Engineers inaugurated a nuclear construction research program to be carried out in conjunction with the AEC. The primary objective of the Corps of Engineers' program was to develop the technology required to assess the engineering feasibility of using nuclear explosives to construct a sea level canal through Central America.[6] The major tasks of the Corps of Engineers in the joint research program with the AEC included:[7]

--Execution of corollary high-explosive cratering experiments in conjunction with the AEC's nuclear cratering experiments.

--Technical participation and assistance in the planning of nuclear cratering experiments.

--Development of the requisite engineering and construction data to be used as the basis for understanding the engineering characteristics of nuclear craters.

The US Army Engineer Nuclear Cratering Group (NCG) was established in 1962 at LRL as the primary agency of the Corps of Engineers for nuclear excavation research and responsibility for technical program direction of the Corps' effort.[8]

THE AEC-CORPS OF ENGINEERS NUCLEAR AND CHEMICAL EXPLOSIVE CRATERING EXPERIMENTS

To develop technology pertaining to the use of nuclear explosives for excavation purposes, the AEC and the Corps of Engineers have conducted a number of cratering experiments in a variety of geologic media using both chemical and nuclear explosives. The data from these experiments have been used to develop methods of predicting crater size and shape in various materials as well as techniques for assessing the potential safety hazards involved in nuclear excavation projects. A total of seven nuclear cratering experiments have been conducted. The code names for these experiments are: Project SEDAN (100-kiloton /kt/ nuclear explosive device); Project DANNY BOY (0.42 kt); Project SULKY (0.09 kt); Project PALANQUIN (4.4 kt); Project CABRIOLET (2.3 kt); Project SCHOONER (35 kt), and Project BUGGY (row of 5 single 1.1 kt devices).[9]

The 100-kt Project SEDAN experiment is the largest explosive charge detonated to date.[10] The nuclear device was detonated on 6 July 1962 at a depth of 635 feet in desert alluvium at the AEC's Nevada Test Site. A crater with an apparent radius of 608 feet and a depth of 323 feet was produced (Figure 4). The

apparent crater volume was 6.6 million cubic yards and the crater lip heights ranged from 18 to 95 feet.[11]

Project DANNY BOY consisted of the detonation of a 0.42 kt nuclear explosive in a dry hard rock at a depth of 110 feet.[12] DANNY BOY was detonated on 5 March 1962 in a rock described as a gray, dense, nonvesecular basalt. The resultant crater had a radius of 107 feet and a depth of 62 feet (Figure 5). The apparent crater volume was approximately 36,000 cubic yards and the avefage lip height was 24 feet.[13]

Project SULKY was designed to investigate the nuclear cratering phenomenon at a depth of burst greater than that at which the optimum or largest apparent crater is produced. A 0.09 kt nuclear explosive was detonated on 18 December 1964 at a depth of 90 feet in the same basalt formation at the Nevada Test Site as Project DANNY BOY.[14] SULKY resulted in a rubble mound (Figure 6).[15] The SULKY experiment was a very valuable one in that it established a distinct point in the range of depths of burst in hard rock at which mounding rather than cratering occurred and provided information on the rock-breaking capabilities of nuclear explosives for quarrying applications.

Project PALANQUIN was detonated on 14 April 1965 in a dense dry rock referred to as porphyritic trachite.[16] The nuclear explosive with a yield of 4.3 kt was buried at a depth of 280 feet and was expected to produce a rubble mound as a further study of quarrying applications. A stemming failure of the emplacement hole occurred, however, which resulted in the very

Fig. 4 - SEDAN 100-kiloton nuclear crater (From Ref. 8)

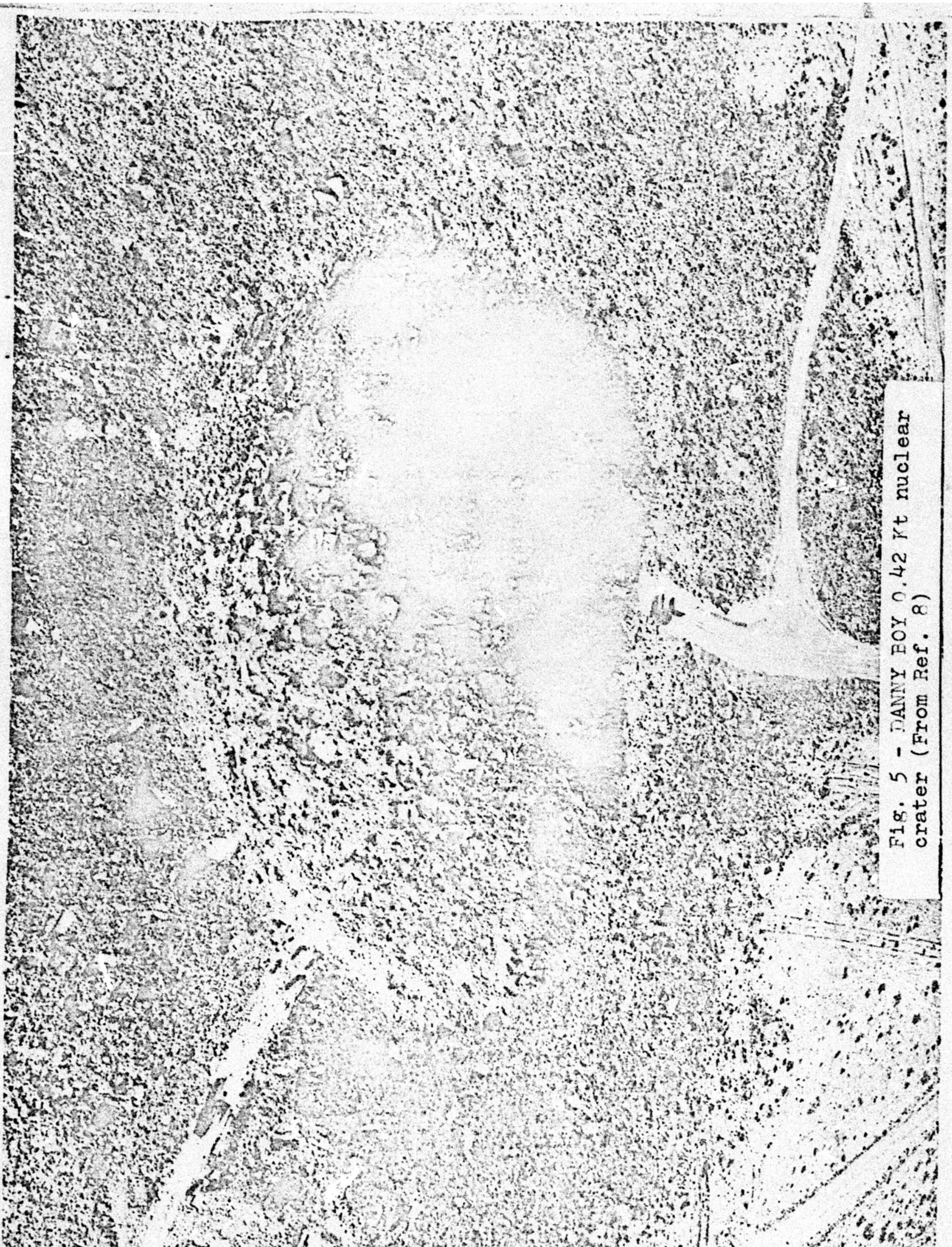


Fig. 5 - DANNY BOY 0.42 Kt nuclear crater (From Ref. 8)

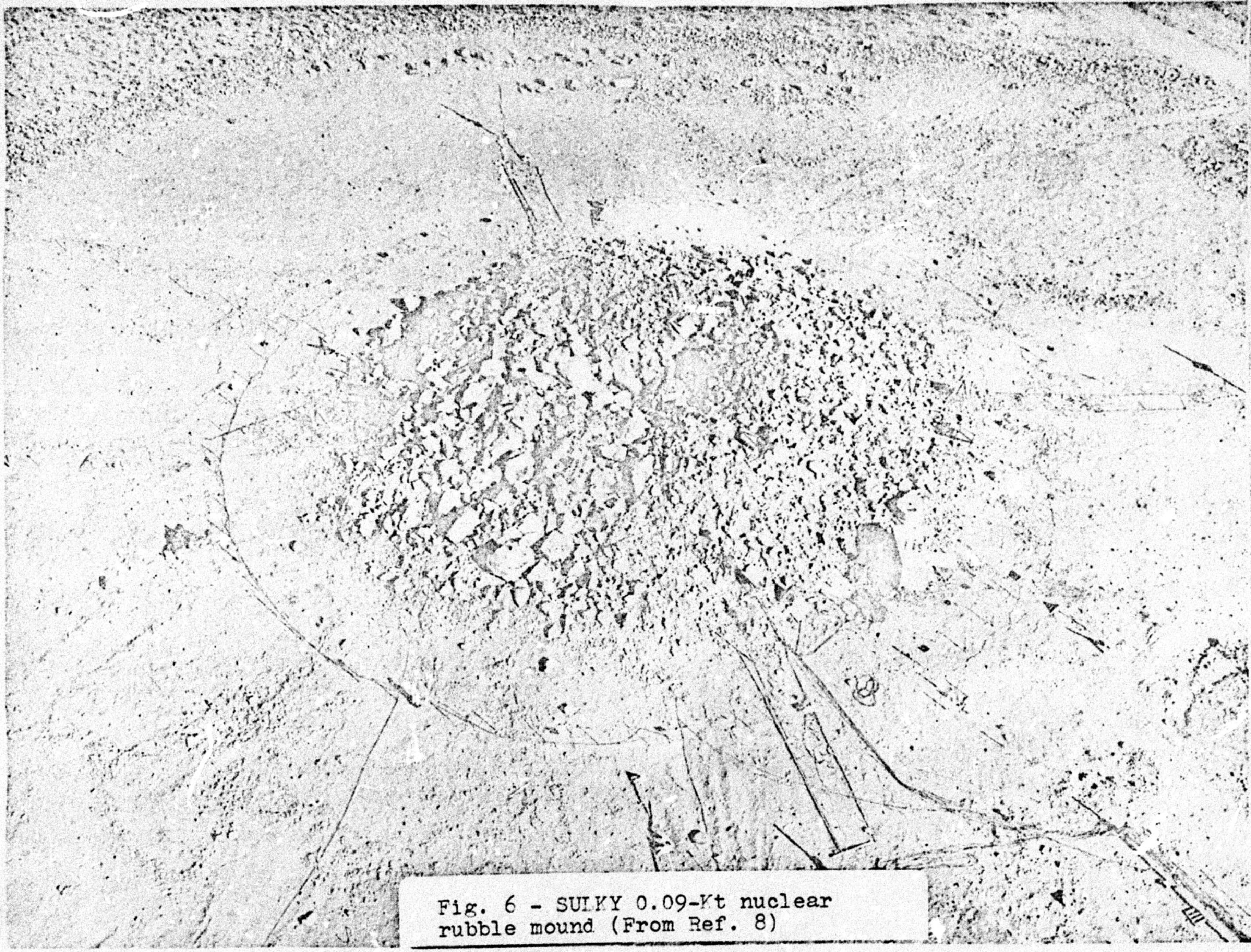


Fig. 6 - SULKY 0.09-Kt nuclear rubble mound (From Ref. 8)

early venting of hot cavity gases and the production of an "erosional" crater. The mechanisms forming such a crater are considerably different from the mechanics associated with normal crater formation as described in Chapter II. The crater dimensions from Project PALANQUIN, therefore, are not considered valid for comparative purposes and are not plotted as cratering data. Figure 7 is a photograph of the PALANQUIN crater. The casing used in the emplacement hole is shown on the crater lip. This casing, which was not firmly grouted to the in-situ media is believed to be responsible for the early venting.[17]

The CABRIOLET 2.3 kt explosive was detonated on 26 January 1968 at a depth of 170 feet in a dense dry, porphyritic trachyte rock similar to that at the PALANQUIN site.[18] The crater produced by this detonation had an apparent radius of 181 feet, a depth of 117 feet and lip height of 31 feet.[19]

The Project SCHOONER experiment was detonated on 8 December 1968 in a tuffaceous rock formation at a depth of 355 feet.[20] A primary purpose of the experiment was to determine the effect of yield escalation on crater size in hard rock. The SCHOONER explosive yield of 35 kt was approximately 15 times larger than that of CABRIOLET. The SCHOONER experiment produced a crater with an apparent radius of 426 feet, an apparent depth of 208 feet and a lip height of 426 feet.[21]

Project BUGGY is the only nuclear row-charge experiment conducted to date. Five nuclear explosives, each with a yield of 1.1 kt, were detonated simultaneously on 12 March 1968, in a dry,

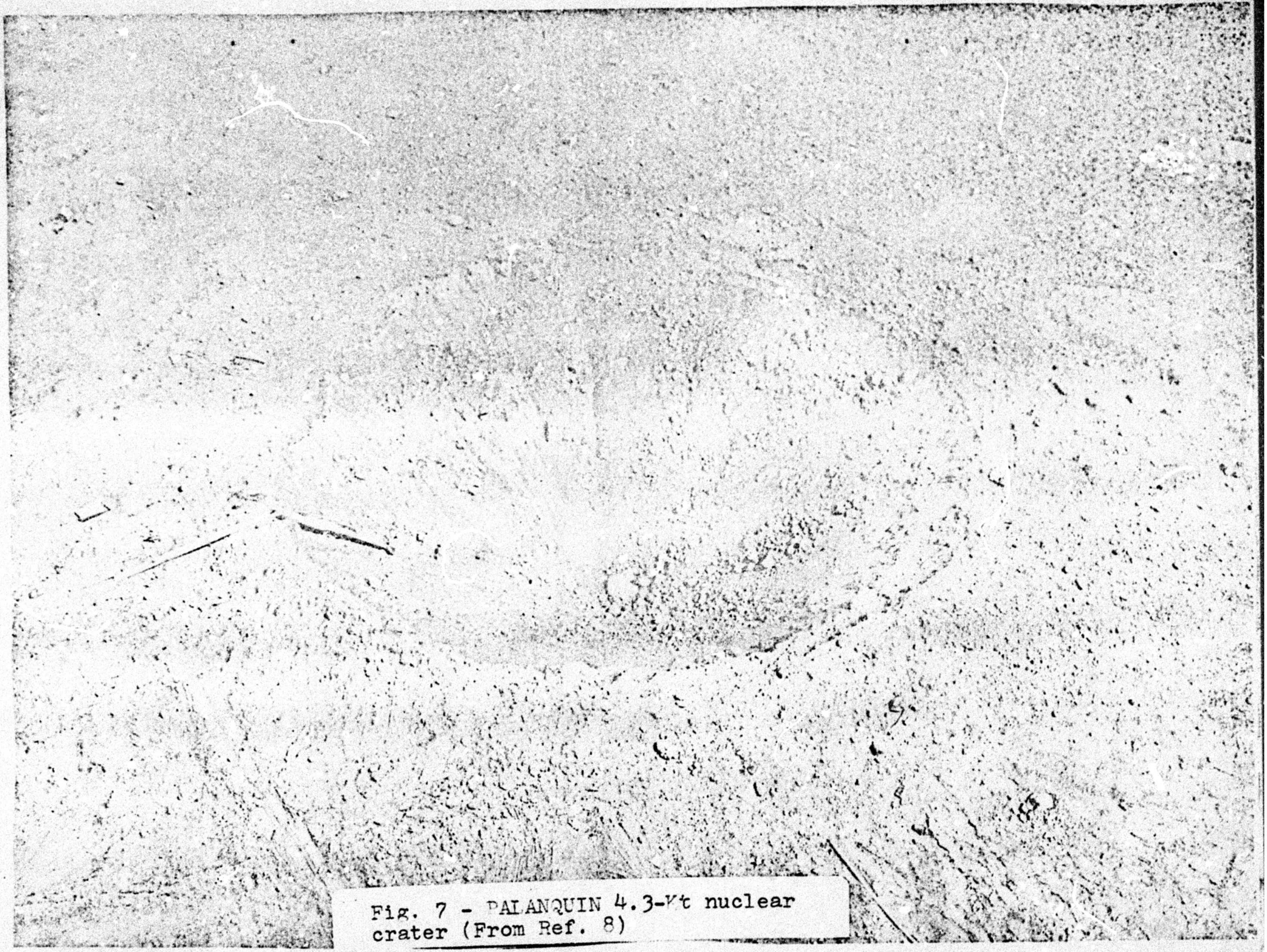


Fig. 7 - PALANQUIN 4.3-Kt nuclear crater (From Ref. 8)

complex basalt formation.[22] The explosives were buried at a depth of 135 feet and spaced 159 feet apart. The channel excavated by the BUGGY detonation (Figure 8) had the following average dimensions:[23]

Apparent crater width--254 feet

Apparent crater depth--65 feet

Apparent crater length--855 feet

Apparent lip height (sides)--41 feet

Apparent lip height (ends)--14 feet

The BUGGY experiment was extremely important to the nuclear excavation research program in that it confirmed the basic concepts of channel excavation derived from chemical explosive experiments at very low yields.

The primary objectives of the chemical explosive cratering experimental program executed by the Corps of Engineers were:

--To provide small-scale forerunners to the high yield nuclear experiments to provide data useful in the design of the nuclear experiments;

--To provide information concerning the engineering properties of crater excavations with reference to their usefulness as engineering structures;

--To develop cratering data in various media of interest such as wet clay shale, which did not exist at the Nevada Test Site;

--To augment the limited nuclear cratering data.

The Corps of Engineers program has included single charge and row-charge cratering experiments in a variety of media to include

Fig. 8 - BUGGY row-charge nuclear crater (From Ref. 8)

desert alluvium, basalt, rhyolite, and clay shale. The explosive charge yields for these experiments range from ½ ton to 100 tons. Pertinent data concerning these experiments are listed in Table I.[24] The craters resulting from the Pre-GONDOLA series in wet clay shale are shown in Figure 9. The chemical explosive experiments conducted by the Corps of Engineers have provided fundamental cratering data upon which large-yield explosive excavation technology is based.

EMPIRICAL CRATERING PREDICTION CURVES

In order to use nuclear explosives to excavate engineering structures, one must be able to predict the size of the excavation resulting from nuclear detonations in the geologic media of concern. One prediction technique which has been developed is based on empirical scaling laws resulting from an analysis of chemical explosive cratering data. Empirical scaling laws are based on the premise that a relationship can be developed which will satisfactorily correlate the dimensional data obtained from explosive detonations of different energy yields. The approach which has been used is based upon the assumption that crater dimensions are proportional to depth of burst; i.e.,

$$\frac{r_a}{R_a} = \frac{dob}{DOB} \text{ and } \frac{d_a}{D_a} = \frac{dob}{DOB}$$

where R_a and D_a are the predicted crater radius and depth for some explosive yield, W, detonated at a given depth of burst, DOB; and r_a and d_a are the crater dimensions for some reference

TABLE I

CORPS OF ENGINEERS CHEMICAL EXPLOSIVE CRATERING EXPERIMENTS
(From Ref 10)

Event (detonation)	Explosive charge per detonation	Material
Single charge experiments		
Pre-Schooner I (four)	20 tons NM*	Basalt
Pre-Schooner II (one)	85 tons NM	Rhyolite
Pre-Gondola I (four)	20 tons NM	Wet clay shale
Multiple charge experiments		
Pre-Buggy I rows (four)	5 at ½ ton NM	Alluvium
Pre-Buggy II rows (eight)	5 at ½ ton NM	Alluvium
Pre-Gondola II row (one)	2 at 40, 3 at 20 tons NM	Wet clay shale
Pre-Gondola III, Phase II, row (one)	7 at 30 tons NM	Wet clay shale
Pre-Gondola III, Phase III, reservoir connection row (one)	1 at 35, 1 at 15, 1 at 10, 2 at 5 tons AL-NH_4NO_3**	Wet clay shale
Project Tugboat, Phase II row (two) array (one)	4 at 10 tons AL-NH_4NO_3	Saturated coral (water overburden)
Project Trinidad, RR1 double row (one)***	44 tons in 32 charges AL-NH_4NO_3	Sandstone and shale

*Liquid explosive nitromethane.

**Aluminized ammonium nitrate slurry blasting agent.

***Fired with a 150-millisecond delay between rows.

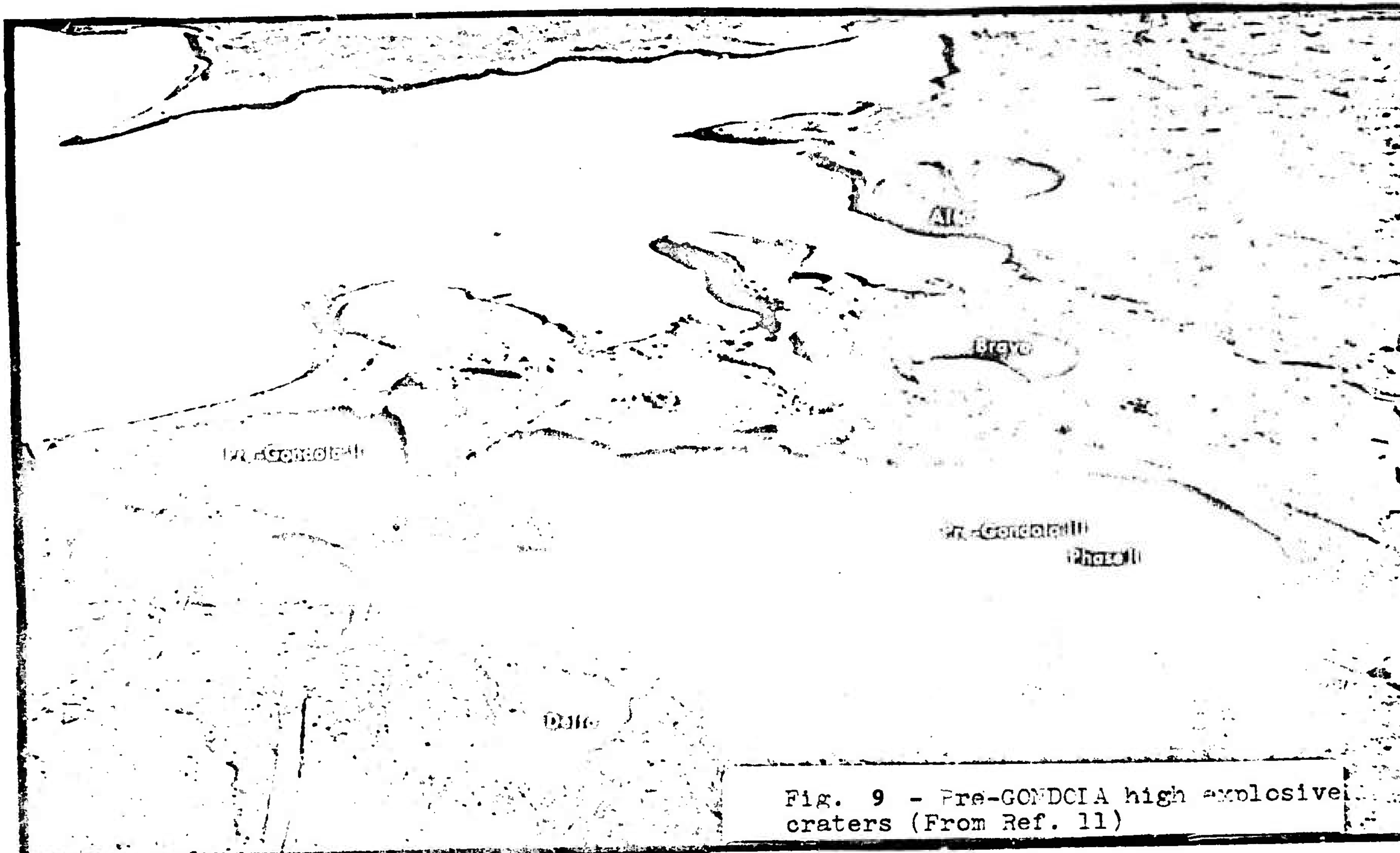


Fig. 9 - Pre-GONDOLA high explosive craters (From Ref. 11)

explosive yield, W_o, detonated at a depth of burst designated by dob. An analytical least squares fit of crater dimensions resulting from the detonation of chemical explosives at varying depths of burst in alluvium was used to develop a functional relationship between crater radius and crater depth and depth of burst; i.e.,[25]

$$\frac{R_a}{r_a} = \left(\frac{W}{W_o}\right)^{1/3.4} ; \frac{D_a}{d_a} = \left(\frac{W}{W_o}\right)^{1/3.4} \text{ and } \frac{DOB}{dob} = \left(\frac{W}{W_o}\right)^{1/3.4}$$

If a reference yield of 1kt is used, these empirical scaling laws may be expressed as:

$$R_a = r_a W^{1/3.4}$$

$$D_a = d_a W^{1/3.4}$$

$$DOB = (dob) W^{1/3.4}$$

where the dimensions r_a, d_a, and dob apply to a crater produced by a 1 kt yield explosive and W is expressed in kilotons.

The 1/3.4 scaling exponent appears to apply to nuclear cratering in rock as well as alluvium. This empirical scaling law has been shown to be valid up to 35 kilotons in rock (Project SCHOONER) and 100 kilotons in desert alluvium (Project SEDAN).

Scaled dimensions are conveniently represented in the forms of curves which show the variation of crater radius and depth as a function of depth of burial. Figures 10 through 12 are curves based on the empirical scaling law which may be used to predict crater dimensions as a function of depth of burst.[26] A close examination of these curves reveals that differences in the physical properties of the materials being cratered may play a more

important role in estimating crater sizes for nuclear excavations than the scaling law used. The smallest scaled craters produced to date have been in hard dry rock and the largest have been in wet weak clay shales. Dimensions for craters in dry soil lie between the extremes for hard dry rock and for weak clay shales. Nonhomogeneous or layered formations are much more difficult to categorize and analyze. No chemical explosive cratering experiments have been conducted to determine the effect of layering on crater dimensions. Three nuclear experiments (CABRIOLET, BUGGY, and SCHOONER) were conducted in layered media out of necessity. Of these three, only BUGGY produced dimensions which were significantly smaller than those predicted on the basis of previous cratering experience in hard rock.[27]

NUCLEAR EXCAVATED SEA LEVEL CANAL STUDY EFFORT

A major portion of the US nuclear excavation research effort has been devoted to the study of the engineering feasibility of using nuclear methods to construct a new sea level canal across the Central American Isthmus. This study was conducted from 1965 to 1970 under the auspices of the Atlantic-Pacific Interoceanic Canal Study Commission, which was established by Public Law 88-609, dated 22 September 1964.[28] This law required the Commission to:

> . . . make full and complete investigation and study, including necessary on-site surveys, and considering national defense, foreign relations, intercoastal shipping, interoceanic shipping, and such other matters as they may

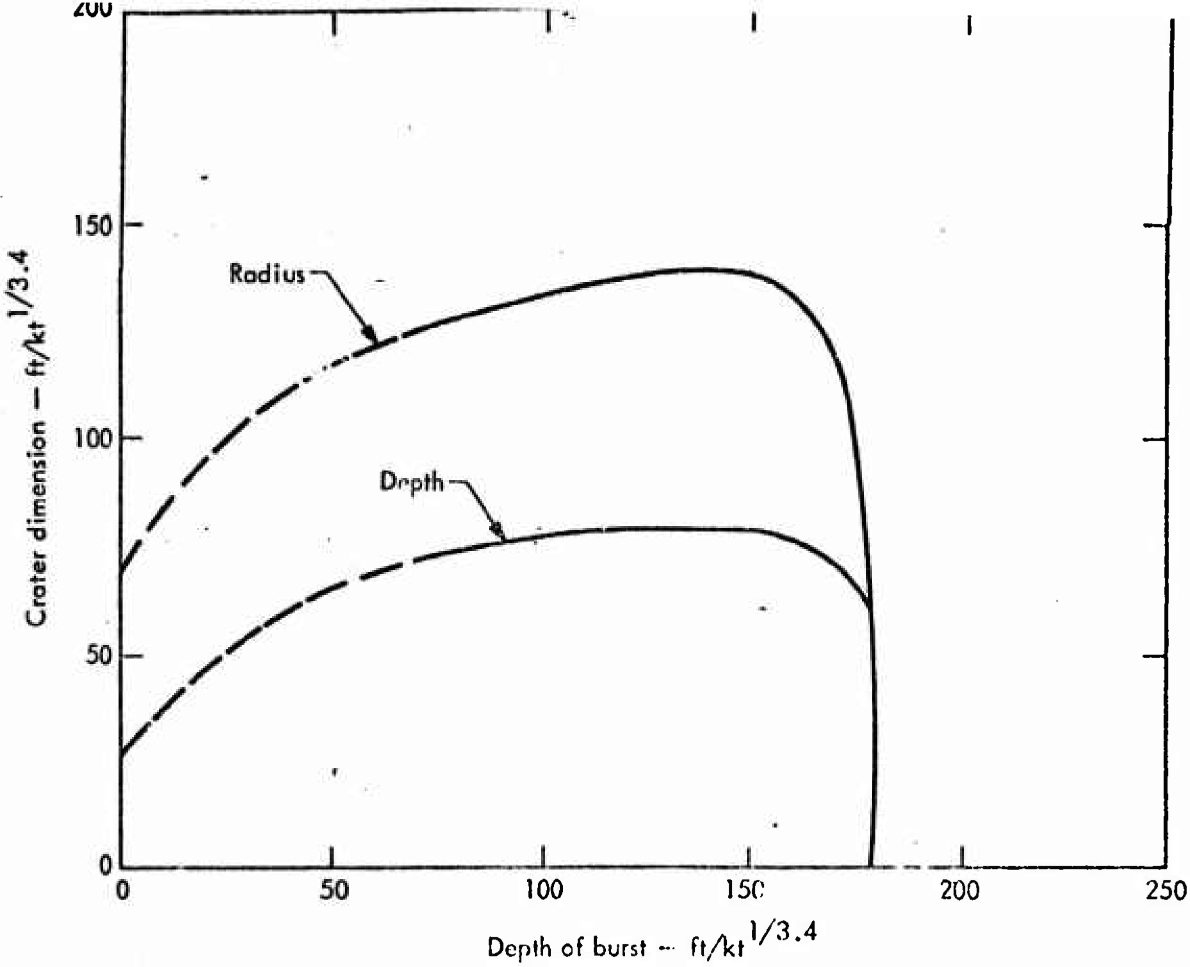


Fig. 10 - Apparent crater dimensions for dry soil (From Ref. 3)

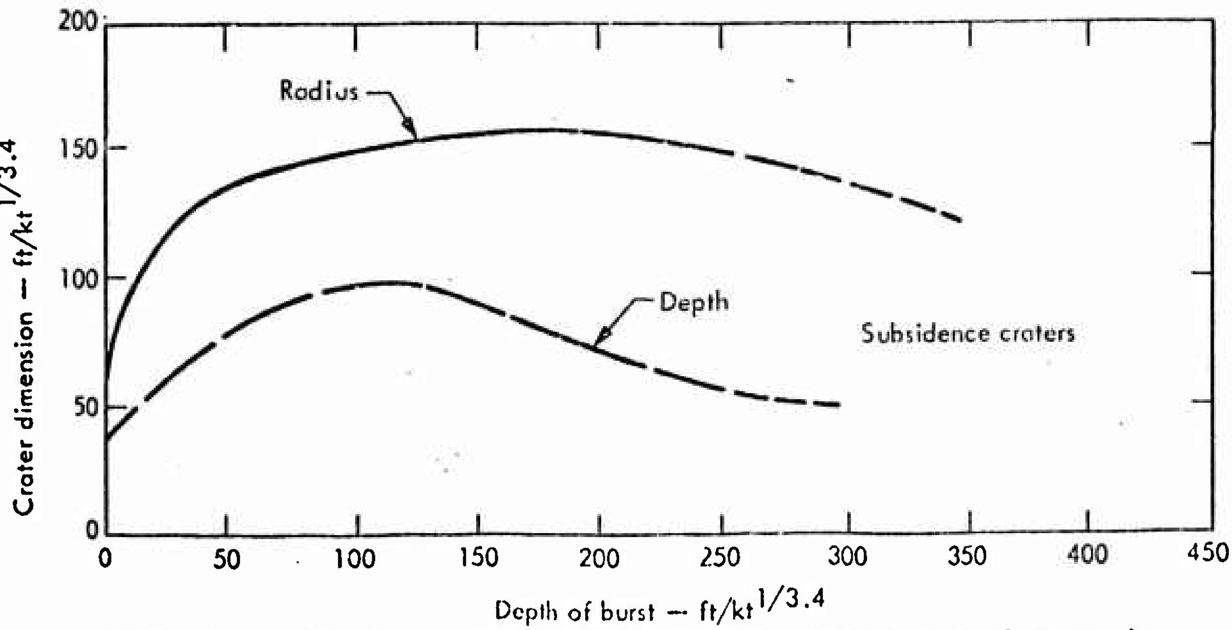


Fig. 11 - Apparent crater dimensions for hard, dry rock From Ref. 3)

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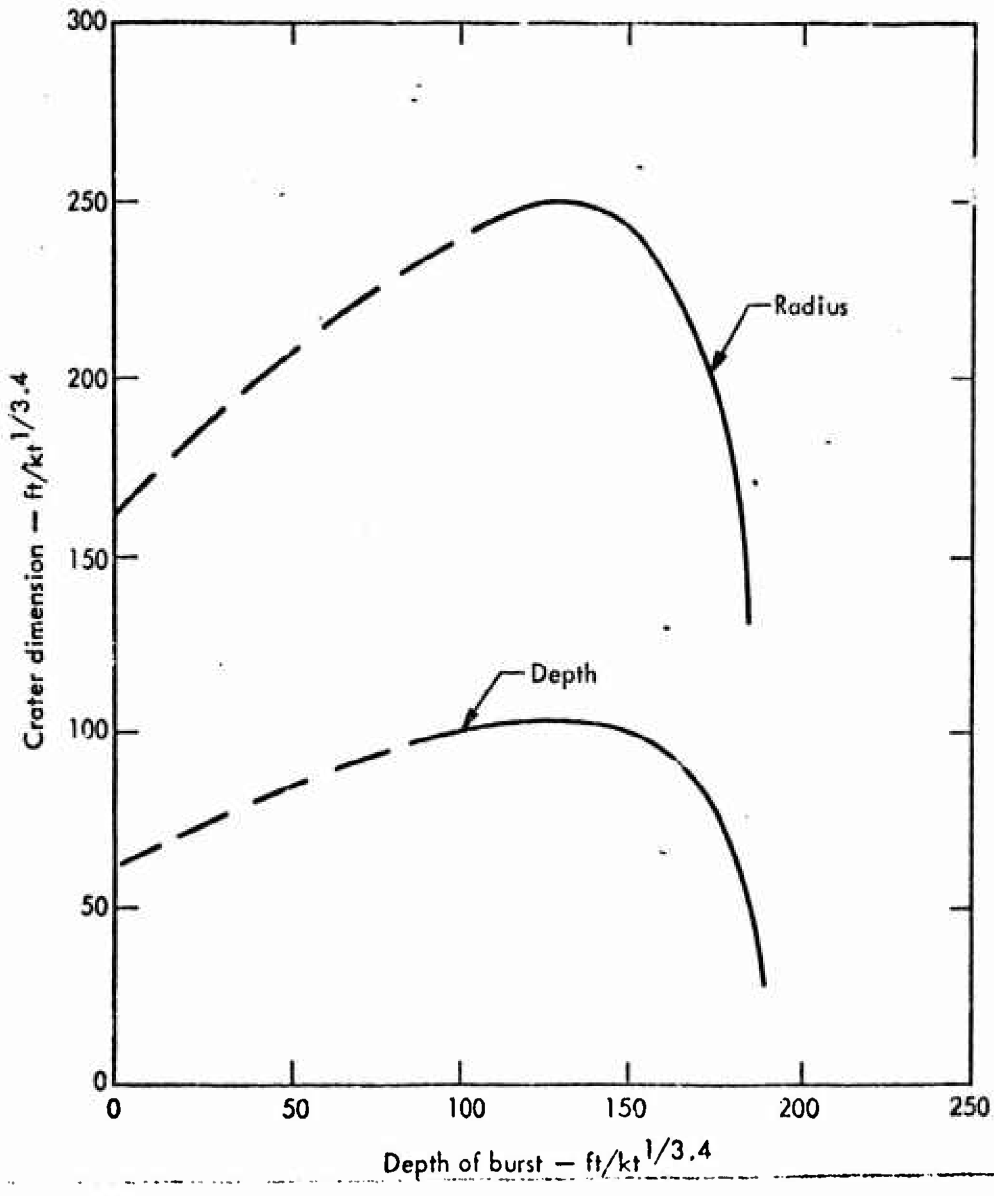

Fig. 12 - Apparent crater dimensions for wet, weak clay shale (From Ref. 3)

> determine to be important, for the purpose of determining the feasibility of, and the most suitable site for, the construction of a sea level canal connecting the Atlantic and Pacific Oceans; the best means of constructing such a canal, whether by conventional or nuclear excavation, and the estimated cost thereof.[29]

The assessment of the engineering feasibility of constructing a nuclear-excavated sea level canal through Central America was accomplished for the Commission jointly by the AEC, the Corps of Engineers, and the Panama Canal Company. The results of all of the nuclear and chemical explosive cratering experiments, as well as on-site subsurface geological investigations and studies to assess the ground motion, air-blast, and radioactivity hazards were used in the assessment.

The nuclear excavation designs described in the feasibility study require explosive yields ranging from 100 kt to 3 megaton.[30] The explosive yields of the nuclear cratering experiments conducted to date were not large enough to verify these nuclear excavation designs. In assessing the status of nuclear excavation technology in its final report, the Commission stated:

> The potential economic advantage of nuclear explosives for large-scale excavation projects is substantial. They should make possible the excavation of cuts of unprecedented size. Although the technology is based on what appears to be sound theory, this theory has been demonstrated by only a limited number of experiments at yield levels much smaller than would be needed for canal construction. The state-of-the art allows predictions of results to be expected from excavation under conditions and at yields different from experience; however, these predictions do not carry the degree of confidence which must exist in an

engineering feasibility study on which nationally significant decisions are to be based. The attainment of such confidence awaits the execution of at least those experiments outlined in Table II. Under present constraints it appears that accomplishment of this experimental program may take as long as 10 years.[31]

Based on this assessment of the status of nuclear excavation technology with respect to sea level canal construction, the Commission stated the following in its letter of 1 December 1970 to the President which forwarded the final study report:

> One provision of the law required us to determine the practicability of nuclear canal excavation. Unfortunately neither the technical feasibility nor the international acceptability of such as application of nuclear excavation technology has been established at this date. It is not possible to foresee the future progress of the technology or to determine when international agreements can be effectuated that would permit its use in the construction of an interoceanic canal. Hence although we are confident that some day nuclear explosions will be used in a wide variety of massive earthmoving projects, no current decision on United States canal policy should be made in the expectation that nuclear excavation technology will be available for canal construction.
>
> The construction of a sea level canal by conventional means is physically feasible. The most suitable site for such a canal is on Route 10 in the Republic of Panama. Its construction cost would be approximately $2.88 billion at 1970 price levels . . .[32]

TABLE II

ADDITIONAL EXPERIMENTS NOW CONSIDERED NECESSARY TO ESTABLISH FEASIBILITY OF NUCLEAR EXCAVATION FOR A SEA LEVEL CANAL
(From Ref 2)

YIELD	TYPE OF EXPERIMENT	PURPOSE
1 mt	Point charge (single crater)	To verify the predicted behavior of saturated rocks; to obtain data on crater dimensions and explosion effects at yields comparable to those required for canal excavation.
5 to 7 charges @100 kt	Multiple point charges (row crater)	To verify concepts of enhancement of row crater dimensions.
5 to 7 charges @100 kt	Multiple point charges (row crater)	To verify techniques of connecting row excavations smoothly.
5 to 7 charges @100 kt to 1 mt	Multiple point charges (row crater)	To demonstrate the techniques of nuclear excavation in a practical project away from the Nevada Test Site.

CHAPTER III

FOOTNOTES

1. K. Parker, "Engineering with Nuclear Explosives--Achievements and Prospects," Journal of the Institution of Nuclear Engineers (Nov/Dec 71), p. 49.

2. Ibid., p. 51.

3. Ibid.

4. Ibid., p. 50.

5. Ibid.

6. Ibid.

7. US Department of the Army, U.S. Army Corps of Engineers Explosive Excavation Research Office (August 1971), p. 3 (hereafter referred to as "Corps of Engineers EERO").

8. Ibid., p. 1.

9. John Toman, Summary of Results of Cratering Experiments (1969), p. 1.

10. Ibid., p. 8.

11. M. D. Nordyke and M. M. Williamson, The Sedan Event (1965), pp. 25-32.

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14. Ibid., p. 10.

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17. F. F. Videon, Project Palaquin--Studies of the Apparent Crater (1966), p. 16.

18. Toman, p. 11.

19. H. A. Tewes, Results of the Cabriolet Excavation Experiment (1968), pp. 31-37.

20. Toman, p. 13.

21. Ibid.

22. Ibid., p. 19.

23. Ibid.

24. "Corps of Engineers EERO," p. 20.

25. M. D. Nordyke, On Cratering; A Brief History, Analysis and Theory of Cratering (1961), pp. 18-40.

26. B. C. Hughes, Nuclear Construction Engineering Technology (1968), pp. 36-37.

27. Toman, p. 6.

28. Atlantic-Pacific Interoceanic Canal Study, Interoceanic Canal Studies 1970 (1970), p. 113.

29. Ibid.

30. Ibid., p. V-179.

31. Robert B. Anderson, Chairman, Atlantic-Pacific Interoceanic Canal Study Commission, letter to the President of the United States, 1 December 1970.

CHAPTER IV

USSR NUCLEAR CONSTRUCTION RESEARCH AND DEVELOPMENT PROGRAM

INTRODUCTION

The Soviet Union has a program, similar to that in the United States, for use of nuclear explosives for peaceful purposes. The magnitude of expenditure by the Soviet Union is not known, but during the past several years the Russians have gradually released considerable information on their nuclear explosive engineering activities.[1] The scope of the Soviet program is described in a booklet, "Atomic Explosives for Peaceful Purposes," edited by I. D. Morokov.[2] This booklet, which was released in September 1970 at the General Conference of the Member States of the International Atomic Energy Agency, describes various aspects of the Soviet Program in peaceful uses of nuclear explosives. Table III summarizes the Soviet Nuclear Explosives for National Economy Program.[3] The section of the table labeled "Proved Applications" lists those Soviet applications which have been successfully demonstrated that are economically feasible, and can be repeated routinely. Those projects listed under "Applications in Development Stage" represent areas in which further experimentation is required. A total of ten Soviet projects have been executed, involving fifteen nuclear explosives in seven types of applications. The listing of proposed projects is indicative of the

TABLE III

SOVIET PROGRAM "NUCLEAR EXPLOSIVES FOR THE NATIONAL ECONOMY"
(From Ref 14)

Applications	Executed Projects: Type	Executed Projects: Explosive	Proposed Projects: Type	Proposed Projects: Explosive
	Proved Applications			
Water reservoir	Experiment crater ("1003")	One 1 kt	Application crater	Two 150 kt
(Crater lip dam)	Experiment crater ("1004")	One 125[a]		
Gas well blowout	Experiment contained Application contained	One 30 kt One 30 kt		
Oil stimulation	Experiment contained	Two 2.6 kt One 8 kt	Application contained	Three 20 kt
	Applications in Development Stage			
Storage	Experiment contained	One 1 kt	Application contained	Two 35 kt
Gas stimulation	Experiment contained Experiment contained	One 25 kt Three 40 kt planned	Application contained	Three 40 kt
Underground mining	Experiment contained	One 1 kt	Experiment contained	One 1.8 kt
Canal	Experiment crater	(T-1) One 0.2 kt (T-2) Three 0.2 kt	Experiment crater Application crater	Single and row 250 explosives
Overburden removal for mining			Experiment crater	Row yield very large
Dam construction (row retarc)			Experiment retarc	Row yield not given

[a]Author estimate.

Soviet interest in the program and their intentions to use nuclear techniques in actual engineering projects as opposed to experiments.

Since the focus of this paper is on potential nuclear construction applications, the following discussion will pertain only to the Soviet cratering applications. The contained applications are primarily for industrial purposes.

SOVIET NUCLEAR CONSTRUCTED RESERVOIR

The Soviet cratering experiments 1003 and 1004 (Table III) were devoted to developing techniques for making a water reservoir with a cratering explosion. The 1003 experiment involved the detonation of 1 kiloton device to create a crater for water storage. In addition, high explosive charges were placed at the expected location of the crater lip before the 1 kt nuclear explosive was detonated. Later the high explosive was set off to provide a channel into the crater.[4]

The follow-on 1004 experiment involved the detonation of a nuclear explosive having a yield of approximately 125 kilotons. This experiment actually produced a reservoir in a stream bed.[5] The significant characteristics of the detonation are as follows:[6]

Rock Formation: sandstone and siltstone

Depth of burst: 200 m

Apparent crater radius: 204 m

Volume of apparent crater: 7 million cubic meters

The Soviets have released a film of the 1004 detonation depicting the explosion and the follow-on construction of a channel through the crater lip to provide an additional reservoir volume of 10 million cubic meters outside the crater using the lip as a dam. The film also indicates that the reservoir is available for boating, swimming, and watering livestock; and that this application of nuclear explosives was completely successful and can be carried out wherever required in any suitable, lightly populated terrain.[7]

As indicated in Table III, the Soviets are planning a project which involves the detonation of two 150 kt nuclear explosives to produce a reservoir with an effective capacity of 27 million cubic meters. The engineering drawings for this project show the layout of the irrigation canal, spillway, and water control works; but there is no indication of where or when the project will be accomplished.[8]

SOVIET CANAL EXPERIMENTS

As indicated in Table III, the Russians have detonated two experiments, T-1 and T-2, to develop data pertaining to the use of nuclear explosives for canal construction. The first detonation (T-1) was a single-charge calibration shot to assist in the design of the follow-on row cratering experiment (T-2). The yield of each of the four nuclear charges used was 0.2 kt. The characteristic dimensions of the channel produced by the T-2 detonation were:[9]

Apparent crater width--61 to 69 meters

Apparent crater depth--15 to 20 meters

Apparent crater length--142 meters

Apparent lip height (sides)--9 to 16 meters

Apparent lip height (ends)--7 meters

The experiments were conducted in a sandstone-siltstone rock formation. This geologic formation apparently contained a significant quantity of gas-forming materials which accounts for the comparatively larger dimensions of the T-2 channel as compared to the BUGGY trench described in Chapter III.

Of particular interest is a well-formulated Soviet proposal to use a combination of nuclear and conventional excavation techniques in constructing the proposed Pechora-Volga Canal.[10] This project would divert the northward-flowing waters of the Pechora River to flow down the Volga to offset the lowering of the Caspian Sea. The Pechora-Volga Canal would be excavated by 250 nuclear explosives. Up to 20 explosives, with a maximum aggregate yield of 3 megatons, would be detonated simultaneously.

PROPOSED SOVIET NUCLEAR DAM EXPERIMENT

The Soviets also have plans to detonate a row nuclear experiment for the purpose of creating a dam.[11] The explosives would be buried in hard rock at a depth such that the rock would be thrown up into the air and fall back to form a mound similar to the SULKY mound. A small scale experiment using multiple high explosive charges has been completed by the Soviets, presumably

as a calibration experiment for the proposed nuclear "mounding dam" experiment.

ASSESSMENT OF SOVIET PROGRAM

The scope of the Soviet nuclear explosives engineering program indicates that they are moving ahead rapidly to develop and apply nuclear excavation technology. The fact that they are actually using the water reservoir created by Experiment 1004, albeit for limited purposes, places the USSR program ahead of the US program which has been limited to nuclear cratering experiments on the Nevada Test Site. The US has accomplished no nuclear experiments in an actual, wet environment such as a river bed. The Soviet's proposed cratering applications are indeed exciting. It will be most interesting to see the extent to which these proposals are implemented.

Morokhov's introductory remarks in his booklet perhaps best summarize the Soviets' optimistic outlook:

> Nuclear explosives for peaceful purposes represent one of the promising new constructive uses of atomic energy. The high economic efficiency of using nuclear explosives to solve many engineering problems hitherto solved with chemical explosives has become obvious. Also, harnessing the energy of nuclear explosions opens up entirely new vistas in the field of explosion technology and offers hope of solving engineering problems whose solution by ordinary means would be unthinkable.[12]

CHAPTER IV

FOOTNOTES

1. Glenn C. Werth "The Soviet Program On Nuclear Explosives for the National Economy," Nuclear Technology, July 1971, p. 280.

2. I. D. Morokhov, Nuclear Explosives for Peaceful Purposes (1970), Foreward.

3. Werth, p. 281.

4. Ibid.

5. K. Parker, "Engineering with Nuclear Explosives--Achievements and Prospects," Journal of the Institution of Nuclear Engineers (Nov/Dec 1971), p. 53.

6. Morokhov, pp. 87-88.

7. Parker, p. 53.

8. Werth, pp. 282-284.

9. Morokhov, pp. 105-106.

10. Werth, p. 297.

11. Ibid., p. 302.

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CHAPTER V

SAFETY CONSIDERATIONS

INTRODUCTION

Any consideration of the use of nuclear explosives for constructive purposes must include a discussion of the hazardous effects which accompany nuclear detonations. These effects are air-blast, ground motion, and radioactivity. While large chemical explosives produce air-blast and ground motion, these effects become much more significant in large nuclear detonations due to the relative size of explosive energies. The release of radioactivity, on the other hand, is a phenomenon unique to nuclear detonations and the primary reason for public reluctance in accepting the concept of using nuclear explosives for civil applications.

As previously mentioned in this paper, one of the objectives of the US nuclear construction research program was the development of technology required to predict and control the effects of radioactivity, air-blast, and ground motion on man and the environment. The following paragraphs outline the current state-of-the-art concerning prediction and control of the effects of nuclear detonations from a nuclear construction point of view.

RADIOACTIVITY[1]

The amount of radioactivity produced by nuclear cratering detonations depends on explosive design and yield, number of

explosives detonated simultaneously, and the geologic media in which the explosions take place. Radionuclides produced by such explosions include residual fissionable and fusionable materials, fission products, thermonuclear reaction products, and activation products resulting from interaction of fission and fusion neutrons with materials composing and surrounding the explosive. Most of these radionuclides emit gamma radiation in the course of their decay to stable nuclides. This gamma radiation is of importance as a source of potential radiation exposure from outside the body, i.e., external radiation exposure. They are also important as a source of potential exposure when radionuclides are taken inside the body, i.e., internal raidation exposure. Another important type of emission in the decay of radionuclides is that of beta particles. These have only a short range in air so their importance is primarily with reference to internal radiation exposure.

Most of the radioactivity produced by a nuclear cratering detonation is buried in the ejecta and fallback material in the immediate area of the crater. The remaining radioactivity is incorporated in the debris cloud produced by the explosion. As the debris clouds are transported away from the detonation site the debris gradually settles to the ground to form a fallout pattern. Most of this radioactivity is associated with larger particles which are deposited in a matter of hours. Material deposited in 24 hours or less is termed "local fallout." A small fraction remains airborne, in gaseous form or attached to very small particles (less than 10 microns), for days, weeks, or longer.

This fraction which becomes what is termed "world-wide fallout," may be carried far from the detonation site before being deposited, primarily in precipitation, during which time concentrations are reduced to insignificant levels by dilution and radiological decay.

The most serious potential radiation exposures to man that would be created by nuclear cratering detonations can be avoided by evacuation of areas near the detonation site. Project personnel would be allowed to reenter the site after the detonation to accomplish follow-on project activities, but their radiation exposure would be limited to acceptable occupational levels and would be subject to continuous monitoring. By means of meteorological control of the time of detonation and fallout predictions prior to any detonation, every effort would be made to limit the deposition of significant levels of radioactivity to areas within the exclusion area. In order that countermeasures could be taken whenever and wherever necessary, monitoring systems would also be established to detect any accidental deposition of unacceptable levels of radioactivity outside of evacuated areas.

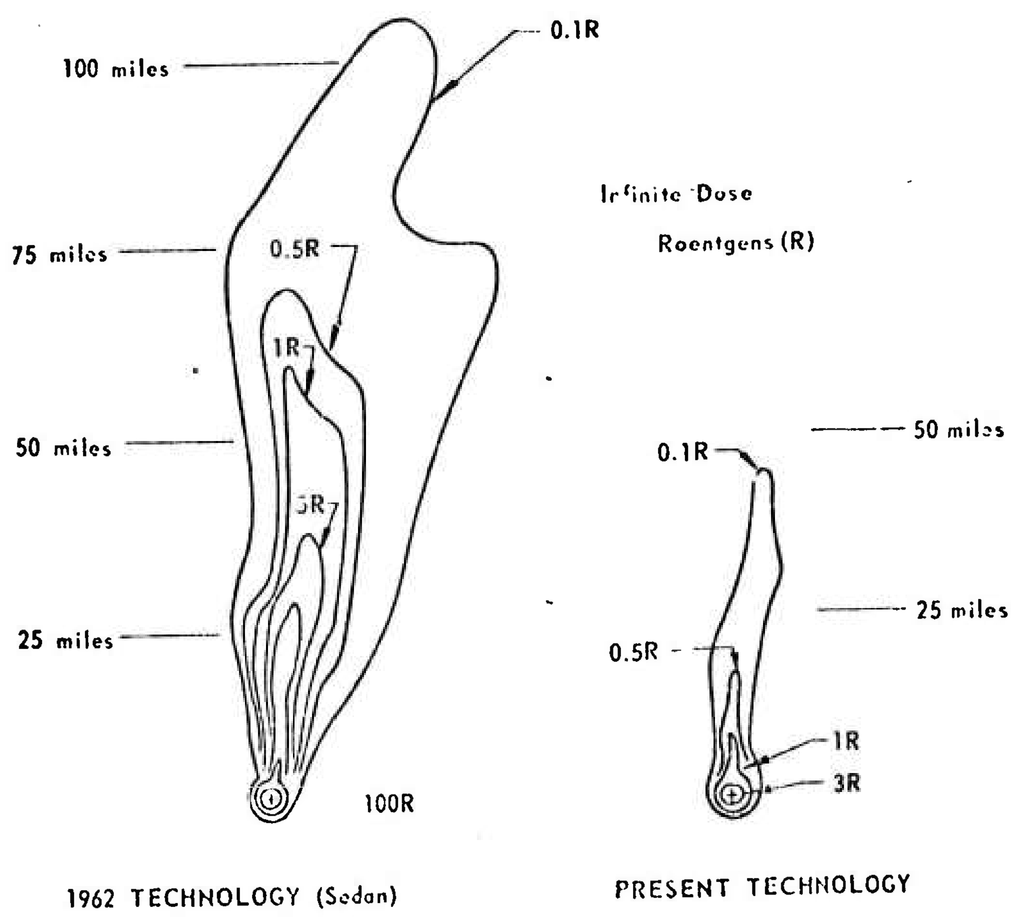
The technical data from the nuclear cratering experiments performed to date together with the improvement in the design of thermonuclear devices have resulted in a very optimistic outlook with respect to radiological safety as it pertains to potential nuclear construction projects. The AEC has stated that it may be assumed that no more than a few kilotons of energy produced by a high-yield Plowshare excavation device will result from the

fission process. The balance of the energy will be produced by the fusion process. The AEC has also stated that the yield of fission products in cloud and fallout may be as low as the equivalent of 20 tons for any given nuclear explosive detonation.[2] Figure 13 shows the relative size of fallout patterns from Project SEDAN, the 100 kiloton explosive detonated in 1962, and a theoretical 100 kiloton explosive of current design.[3] Briefly, the tremendous decrease in the size and extent of the fallout pattern is due to the development of "minimum-fission" thermonuclear explosives, special emplacement techniques, use of extensive neutron shielding, and the significant scavenging effect of ejecta and fallback.

GROUND MOTION[4]

As discussed in Chapter III, a nuclear cratering detonation generates a high-amplitude shock front and disrupts large quantities of material. Most of the energy of the shock front is transferred to the medium in the vicinity of the explosives. At some distance from the point of detonation, the particle motion becomes elastic and radiates outward as a seismic pulse or ground motion. That fraction of the total energy released by the nuclear detonation which is ultimately observed as long-range ground motion is less than one per cent. The seismic amplitudes attenuate with increasing distance due to geometrical divergence and further energy losses to the propagating medium.

'Y



Reduction of radioactive fallout from a 100-kiloton detonation.

Fig. 13 - Comparative Fallout Patterns 1962-Present (From Ref. 10)

Attempts have been made to correlate the seismic phenomena of a nuclear detonation to the effects of natural earthquakes. Although similarities exist, the differences in the source mechanisms and depths of earthquakes and nuclear detonations make the character and spectrum of the respective oscillations measurable different. Earthquakes are usually characterized by lower frequencies and longer durations than are the seismic motions from nuclear detonations. The motions become more similar, however, as the yield of the detonation is increased.

The magnitude of ground motion at a given distance from the detonation depends on explosive yield, depth of burial of explosive, properties of the medium at the detonation point, propagation path, and subsurface conditions at the receiving point.

Personnel safety as well as property damage must be considered when assessing the hazards of ground motion. For close-in ground motion effects, injury to personnel is avoided by evacuation of the critical area in the immediate vicinity of the detonation. The extent of this evacuation area will be determined by radiological safety considerations rather than ground motion. At greater distances, the level of ground motion would be insufficient to cause direct personnel injuries. Any potential injuries to be considered would be those associated with damage to structures. The susceptibility of any manmade facilities to structural damage from ground motion would have to be assessed for any proposed nuclear cratering detonation. The empirical data developed to date from nuclear cratering experiments and earthquakes makes

such an assessment possible. Based on this assessment of potential structural damage, a maximum yield could be specified which would be considered safe for detonation without causing personnel injuries or inacceptable property damage. This approach to seismic safety, of course, places constraints on the location of potential nuclear cratering projects. These constraints, however, would be no greater than those imposed by radiological safety considerations.

AIRBLAST[5]

Very soon after a nuclear cratering explosion, a high-pressure wave (or blast or acoustic wave) develops in the air and moves rapidly away from the explosion point, behaving like a wall of compressed air. When the blast wave strikes the ground or other solid surface it is reflected, and may also be of concern until its energy is depleted to a low level. This wave may also be reflected, and under certain conditions focused by layers of the atmosphere. The magnitude of the air blast signal depends on which of the two primary mechanisms, spall or gas vent, dominates in coupling energy to the atmosphere. This depends on the yield of explosive, the geoenvironment and the depth of burial of the explosive. The air blast signal may be considered in the categories of close-in and long-distance. The long-distance signal may extend to several hundred miles. The safety concern from both categories of air blast signals is damage to structures, particularly windowpanes, and possible injury to personnel

resulting from structural failures. Close-in air blast effects are caused by direct air blast pressure on structures. Long-distance effects are caused by atmospheric propagation and focusing under certain high-altitude meteorological conditions.

Close-in air blast problems are avoided by evacuating all personnel from the immediate vicinity of the detonation, as was the case for ground motion. Long-distance effects are avoided by selecting a time for the explosion when high-altitude meteorological conditions preclude air blast waves being refracted and focused to a hazardous degree.

ASSESSMENT OF SAFETY CONSIDERATIONS

Considerable knowledge has been obtained concerning the nature, extent, and methods of predicting and controlling the hazardous effects of nuclear cratering detonations up to 100 kilotons in yield. The potential radiological hazard has been significantly reduced but not eliminated. All nuclear cratering detonations will release some radioactivity. For this reason, and to preclude close-in injuries from ground motion and air blast, an evacuation area would have to be established in the immediate vicinity of the detonation. Project personnel could reenter this exclusion area on a limited-time basis shortly after the detonation under carefully monitored conditions.

The off-site hazards from a nuclear cratering detonation can be minimized or eliminated by proper selection of the detonation time and limiting the yield of the detonation. These measures,

in addition to possible temporary evacuation of certain off-site structures, will preclude any personnel injuries and unacceptable damage to structures from ground motion or air blast.

As discussed in Chapter III, higher yield experiments are required to assess the potential safety hazards resulting from detonations higher in yield than 100 kilotons to include multiple-charge detonations. Several types of applications could be accomplished, however, within the 100 kiloton yield limit as is evidenced by the work accomplished in the USSR and discussed in Chapter IV.

CHAPTER V

FOOTNOTES

1. US Atomic Energy Commission, Nevada Operations Office and US Army Engineer Nuclear Cratering Group, "Nuclear Excavation Technology," in Interoceanic Canal Studies, 1970, Annex V, Appendix III, pp. B34-E3.

2. Bernard C. Hughes, Nuclear Construction Engineering Technology (1968), p. 80.

3. US Atomic Energy Commission, p. G5.

4. Ibid., pp. E20-E24.

5. Ibid., pp. E14-E19.

CHAPTER VI

POTENTIAL MILITARY NUCLEAR CONSTRUCTION APPLICATIONS

INTRODUCTION

The primary US interest in the uses of nuclear explosives for excavation purposes was closely tied to the potential for using such techniques for sea level canal construction.[1] Since the determination in 1970 that the nuclear engineering technology had not sufficiently advanced to provide a basis for statement of engineering feasibility for sea level canal construction, the US nuclear excavation research program has become essentially dormant. No funds have been approved for the follow-on higher yield nuclear experiments outlined in Table II, and there has been no further development of special nuclear excavation explosives. The limited AEC Plowshare effort is currently devoted almost entirely to contained industrial applications. The Corps of Engineers has disestablished the Nuclear Cratering Group and established the Explosive Excavation Research Office which is placing primary emphasis in research on the use of large-scale chemical explosives in construction projects.[2]

The technology developed to date in the nuclear construction research program indicates that nuclear construction techniques might indeed play a vital role in a hostile military environment in which expediency is of the utmost importance and safety criteria would of necessity be much less stringent than the present,

peacetime, US standards. It would be appropriate then to discuss those civil applications which have been considered to date which may have potential military construction application. The technology developed in the civil programs could be most useful as a base for developing military construction techniques which we would be prepared to use in support of hostile, military operations. The following paragraphs describe several potential military construction projects using nuclear explosives.

NUCLEAR QUARRYING

The subsurface detonation of a nuclear explosive has the potential for producing a large volume of broken rock at a low unit cost. Military operations require tremendous quantities of rock for construction and repair of all types of ground lines of communications and engineering facilities. Rather than using the time-consuming, conventional quarrying methods, nuclear detonations could be used to produce quarry rock with minimum effort, in minimum time.

The basic concept of using nuclear explosives for quarrying purposes is to detonate the device at such a depth that the quantity of broken rock is maximized and the distance to which the rock is ejected is minimized. In order to facilitate removal of the rock after the detonation and to facilitate subsequent operations of the quarry, a hillside having an inclination of approximately 30 degrees would be the most advantageous topographic environment for nuclear quarrying projects. Ideally, the rock

Fig. 14 - Nuclear quarry concept
(From Ref. 11)

would be broken and bulked and a minimum amount would slide downhill. If the slope is too steep, an excessive volume of rock will be scattered downhill and if the slope is not steep enough, it will be necessary to excavate deep into the crater to recover the rock. Either extreme will greatly hinder removal and subsequent use of the quarry rock.

The SULKY detonation in December 1964 provided information of significant value with respect to the nuclear quarrying concept. The configuration resulting from the SULKY detonation was a mound of rock which projected above the predetonation ground surface (Figure 6) rather than the more classical crater. A concept of nuclear quarry in operation is shown in Figure 14.

NUCLEAR HARBORS

Military operations in the past have always required new areas for debarking and embarking men, supplies, and equipment. The concept of using nuclear explosives to produce protected water areas of sufficient depth to facilitate entry, unloading, and exit of both deep draft vessels and lighter craft is most intriguing. The crater formation process, in addition to creating an excavation of the required depth, also results in the formation of a crater lip which may well function as a breakwater to protect the harbor area from wave action. It may be necessary to provide an entrance channel for a harbor which is sited some distance inland from the shore line. If an entrance channel is required, consideration should be given to using a nuclear-excavated cut as

discussed later in this chapter. The nuclear construction aspects of the harbor would then involve the detonation of a single explosive to produce the harbor area itself as well as the detonation of a row of explosives to excavate the entrance channel. The yields of the nuclear devices required would, of course, depend on the draft depth and width and the number of vessels to be accomodated. A concept of this application is shown in Figure 15.

NUCLEAR-EXCAVATED CUTS

Construction requirements in support of military operations could well require excavation of a roadway cut to expedite road construction through hilly, irregular terrain. Rather than using time-consuming conventional earthmoving techniques requiring tremendous manpower and equipment resources, it may be feasible to accomplish the required excavation by nuclear methods. A series of nuclear explosives could be detonated simultaneously in a row to produce a linear crater. With some remedial conventional construction effort, this linear crater could function as the roadbed. For a roadway cut of considerable length, it may be necessary to excavate the cut by a series of linear craters which are interconnected rather than by a single linear crater. Figure 16 depicts the concept of a nuclear-excavated highway cut.

Other possible applications of nuclear-excavated cuts include the construction of inland navigable waterways or water diversion channels.

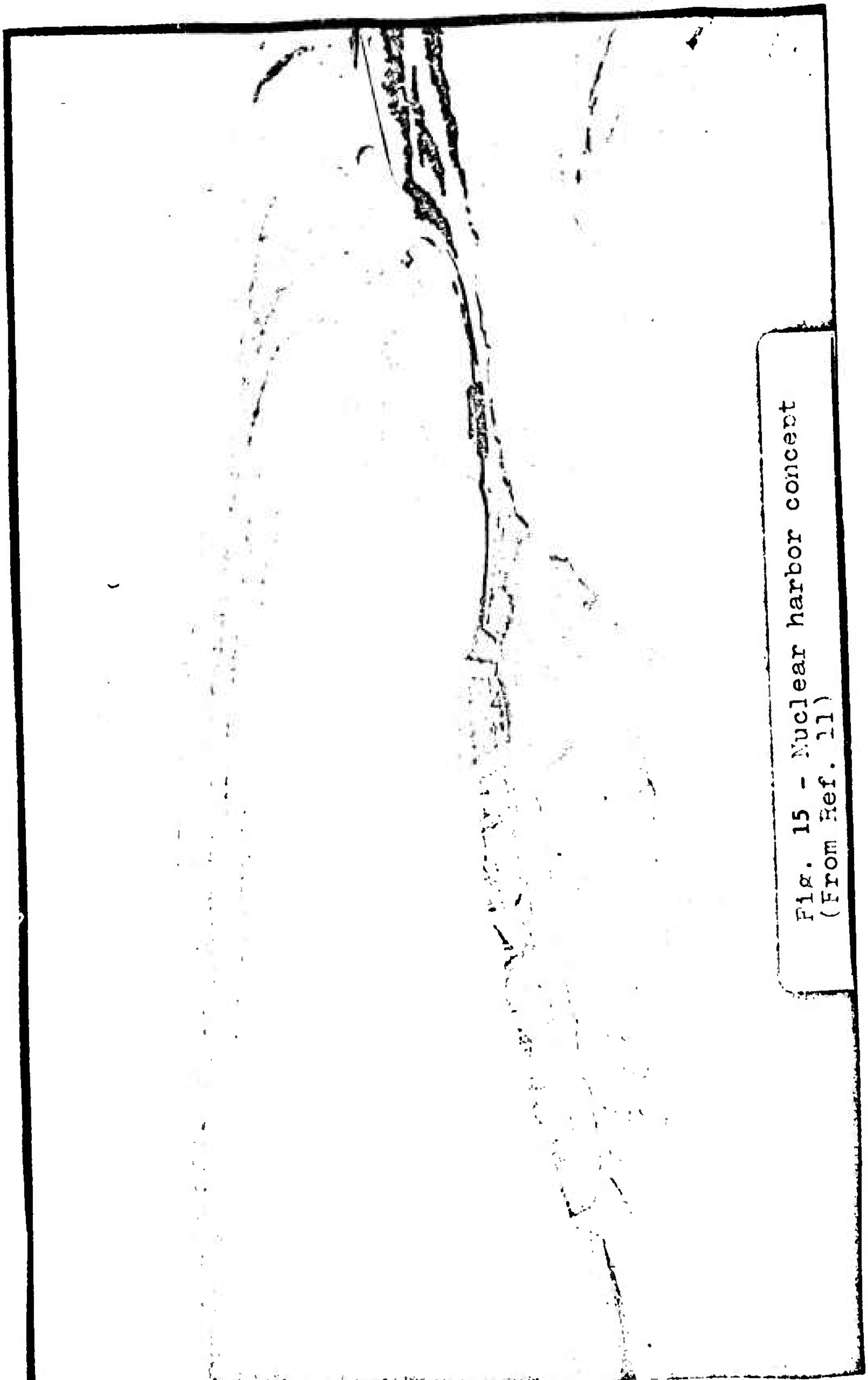


Fig. 15 - Nuclear harbor concept
(From Ref. 11)

NUCLEAR EJECTA DAM CONCEPT

The three potential military nuclear construction applications discussed thus far in the chapter are rather straight forward and unsophisticated. A more complex application which might be required on a more limited basis would be the construction of a nuclear ejecta dam. This concept involves the detonation of a nuclear explosive in the wall of a canyon to eject material across the canyon and thereby create a water storage embankment. In addition to the material actually ejected into the canyon, it is reasonable to assume that some material may collapse from the region immediately above the true crater boundary and add to the total volume of embankment material. In addition to the nuclear detonation itself, of course, consideration would have to be given to the practical engineering aspects of dam construction, such as an impermeable embankment seal, settlement of ejecta material, and seepage through the embankment. Conventional follow-on construction techniques would have to be used to reshape the ejecta into the desired configuration and to place an impermeable seal on the upstream face of the dam.

The proposed nuclear dam construction experiment described in Chapter IV will provide significant information on the potential practicality of the nuclear ejecta dam concept.

Fig. 16 - Nuclear-excavated highway cut concept (From Ref. 11)

CHAPTER VI

FOOTNOTES

1. K. Parker, "Engineering with Nuclear Explosives--Achievements and Prospects," Journal of the Institution of Nuclear Engineers (Nov/Dec 1971), p. 50.

2. US Department of the Army, US Army Corps of Engineers Explosive Excavation Research Office (August 1971), p. 1.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The US nuclear construction research program conducted by the US Atomic Energy Commission and the Corps of Engineers has provided significant data pertaining to:

--An understanding of single-charge cratering mechanisms and techniques for predicting crater size and shape up to nuclear yields of 100 kiloton.

--A basic understanding of simultaneous multiple-charge cratering mechanisms to produce linear craters for the low-yield nuclear explosives.

--An understanding of the engineering properties of nuclear craters produced by nuclear yields up to 100 kiloton.

--An understanding of the nature and magnitude of the hazardous side effects of air blast, ground motion, and radioactivity which accompany nuclear cratering detonations and the steps which must be taken to prevent personnel injuries and unacceptable property damage to include exclusion areas in the vicinity of the detonation.

--Techniques to minimize the release of radioactivity from nuclear cratering detonations through development of "minimum fission" thermonuclear explosives, special emplacement techniques, and extensive neutron shielding.

The most significant single element of the US nuclear construction research program has been the study to determine the engineering feasibility of using nuclear methods to construct a sea level canal through Central America. Due to the limited number of nuclear cratering experiments at yields far less than the maximum yield required for sea level canal construction, a sufficient degree of confidence could not be attached to the current nuclear construction state-of-the-art to support a confirmation of engineering feasibility for using nuclear methods. A series of larger yield single and row-charge experiments have been identified as necessary to establish feasibility of nuclear excavation for a sea level canal, but no action is currently underway to accomplish these or any other nuclear cratering experiments.

The US nuclear construction research program has accomplished much in establishing the basic technology. No application projects, however, have been undertaken and the safety and engineering refinements required to use this technology in actual applications remain to be accomplished.

The USSR nuclear construction research program appears to be moving ahead rapidly in the development and application of nuclear excavation engineering. The Soviets have one nuclear reservoir project which is actually being used and several large-scale application projects scheduled for execution.

The availability of a nuclear construction capability to support military operations could significantly enhance the effectiveness of the US fighting forces. The technology developed for

civil applications could be used as a base for developing a military capability to use nuclear explosives to construct roadway cuts, water diversion channels, harbors, and similar facilities. Due consideration would have to be given to personnel safety in a hostile, military environment, but the safety constraints would be much less severe than the US peacetime standards.

RECOMMENDATIONS

Based on an assessment of the potential savings in manpower, time, and money which could result from the use of nuclear construction methods to support military operations, it is recommended that:

1. The Department of the Army develop and incorporate in its doctrine the use of nuclear construction techniques in support of military operations.

2. The technology developed under the US nuclear construction research program for civil applications should be used as a basis for further developing the required military technology.

3. The scope of the development effort includes:

a. Additional nuclear cratering experiments in the appropriate yield range to refine the safety and engineering data required for nuclear military applications.

b. Design and fabrication of nuclear excavation explosives specifically designed for military nuclear construction applications.

c. Training of appropriate military personnel so that the nuclear construction technology can be knowledgeably applied in the field.

BERNARD C. HUGHES
LTC CE

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3. Hughes, Bernard C. Nuclear Construction Engineering Technology. NCG Technical Report No. 2. Livermore, California: US Army Engineer Nuclear Cratering Group, 1968.

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